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REPORT ON MECHANICAL TESTING TO EVALUATE THE SAFETY OF 120-MM MORTAR DESIGNS

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20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

Safe maximum operating pressure curves were developed for three candidate 120-mm mortar designs. The safe maximum operating pressure curve is the elastic strength pressure of the mortar when the material is at the maximum operating temperature. To produce these curves, the strength properties of the three materials at elevated temperatures were measured. These properties were then used to determine the elastic strength pressures of the individual mortar designs. This analysis is necessary to determine margins of safety.

(CONT'D ON REVERSE)

20. ABSTRACT (CONT'D)

Additionally, the fracture properties of the various materials were determined at various temperatures, and an assessment of the likelihood of brittle fracture of the various designs was made.

Keywords; previous page

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INTRODUCTION

To determine if a mortar can be safely operated under its design conditions, several parameters must be understood. Among these are mortar geometry, the design pressure, and the mechanical properties of the material from which the weapon is made. This report deals with the measurement of the mechanical properties of mortar materials and how these properties are used to determine safety.

When a mortar made from a high strength steel is fired, two weapon responses can occur making it unsafe to operate further or even fail during firing. The weapon can either bulge due to overpressure or it can fail in a brittle manner. These two competing processes always exist. Factors that affect the bulging are the mortar dimensions and the yield strength of the mortar material at the operating temperature. Factors that affect the brittle failure of the weapon are the wall thickness of the weapon, the yield strength, and the fracture toughness of the material at the operating conditions.

ANALYSIS

To determine the safe operating pressure of the weapon, we must know the yield strength of the material and the cross section dimensions of the weapon as shown in Figure 1. The pressure that causes yielding is given by the following equation:

$$\text{Max Pressure} = \text{Yield Strength} \times \frac{k^2 - 1}{\sqrt{(3k^4+1)}} \qquad (1)$$

Since the yield strength varies with operating temperature, the maximum safe operating pressure also varies with operating temperature. The value of k, the radius ratio, varies with position along the length of the tube.

To determine the conditions under which brittle fracture occurs, we assume that fracture occurs when the wall thickness of the tube (W=b-a, from Figure 1) is large enough for linear elastic fracture mechanics to be applicable. This means that the conditions may be present for the tube to fail without any warning. Equation (2) relates tube geometry to material properties

$$W > 5.0 \times \frac{(\text{Fracture Toughness})^2}{(\text{Yield Strength})^2} \tag{2}$$

The possibility of brittle fracture is really very small in mortars, first, because they are very thin-walled vessels and second, because of the temperature effect on fracture toughness and yield strength. As the temperature increases, the fracture toughness increases and the yield strength decreases, therefore the minimum wall thickness increases with increasing temperature. Since mortars heat up during firing, the possibility of brittle fracture should be remote. The brittle fracture analysis is included for completeness.

TESTING RESULTS

The tensile properties for the material supplied by three contractors are given in Table I at various temperatures. The fracture properties of the material at the same temperatures are given in Table II. All of the properties reported in the tables were obtained from two different tubes and are the average of from three to five different specimens.

The maximum safe operating pressures are given in Figure 2 for Contractor A; Figure 3 for Contractor B; and Figure 4 for Contractor C. As stated above, the maximum safe operating pressures are a function of yield strength (which varies with temperature) and tube dimensions (which vary with position along the tube). The maximum safe operating pressures are presented only at the maximum operating temperature (MOT) for each contractor. A 0.2 percent offset yield strength was used and the margin of safety was the difference between the maximum safe operating pressure and the design pressure normalized with respect to the design pressure. This calculation cannot be made without contractor-supplied design pressure data.

The minimum wall thickness that may result in brittle fracture, along with the fracture toughness properties, is given in Table II. If the tube wall thickness is less than that given in the table, the tube will bulge before fracture. The maximum wall thickness of each of the designs is also given in Table II. It is clear that all of the mortars are brittle fracture-safe.

TABLE I. TENSILE TEST RESULTS

Contractor A - Longitudinal Specimens					
Temperature	0.1% YS (Ksi)	0.2% YS (Ksi)	UTS (Ksi)	% EL	% RA
72°F	156.9	162.2	177.4	34.9	57.8
250°F	147.4	150.2	168.7	29.2	50.9
500°F	142.0	143.7	166.7	42.7	53.4
MOT (807°F)	124.3	127.2	145.0	33.9	76.8
Transverse Specimens					
Temperature	0.1% YS (Ksi)	0.2% YS (Ksi)	UTS (Ksi)	% EL	% RA
72°F	162.7	166.9	180.3	25.0	58.3
250°F	145.4	156.7	166.8	20.4	50.5
500°F	141.0	147.6	163.6	20.6	54.9
MOT (807°F)	126.9	133.9	148.0	23.9	81.0
Contractor B - Longitudinal Specimens					
Temperature	0.1% YS (Ksi)	0.2% YS (Ksi)	UTS (Ksi)	% EL	% RA
72°F	138.0	141.5	157.4	23.9	54.9
250°F	130.3	134.2	149.5	23.4	56.4
500°F	121.3	122.7	145.7	22.5	59.0
MOT (662°F)	119.6	122.8	141.7	21.8	59.7
Transverse Specimens					
Temperature	0.1% YS (Ksi)	0.2% YS (Ksi)	UTS (Ksi)	% EL	% RA
72°F	136.9	140.0	155.2	22.0	52.1
250°F	127.3	135.7	142.8	13.6	49.1
500°F	117.5	122.0	138.7	20.6	63.4
MOT (662°F)	115.0	119.5	140.0	14.2	52.6

TABLE I. (CONT'D)

Contractor C - Longitudinal Specimens					
Temperature	0.1% YS (Ksi)	0.2% YS (Ksi)	UTS (Ksi)	% EL	% RA
72°F	173.0	178.9	206.4	16.5	32.2
250°F	163.4	169.5	196.0	15.3	39.1
500°F	151.8	158.8	193.0	25.0	40.5
MOT (783°F)	144.0	150.9	178.0	23.4	62.0
Transverse Specimens					
Temperature	0.1% YS (Ksi)	0.2% YS (Ksi)	UTS (Ksi)	% El	% RA
72°F	185.0	189.6	208.8	13.9	22.3
250°F	171.3	175.3	196.0	10.7	20.0
500°F	165.0	166.8	183.0	17.0	19.8
MOT (783°F)	138.8	149.8	175.0	20.6	34.2

YS - yield strength
UTS - ultimate tensile strength
EL - elongation
RA - reduction-in-area

TABLE II. FRACTURE TOUGHNESS TEST RESULTS

Contractor A: Maximum Wall Thickness = 0.550 in. Longitudinal Specimens		
Temperature	K_{Ic} (Fracture Toughness)	$5(K_{Ic}/YS)^2$ = Minimum Wall Thickness
	(Ksi$\sqrt{in.}$)	(in.)
-40°F	168.1	5.37
75°F	155.8	4.61
250°F	173.1	6.64
500°F	147.4	5.26
MOT (807°F)	216	14.42
Transverse Specimens		
Temperature	K_{Ic} (Fracture Toughness)	$5(K_{Ic}/YS)^2$ = Minimum Wall Thickness
	(Ksi$\sqrt{in.}$)	(in.)
-40°F	154.3	4.27
75°F	156.3	4.39
250°F	151.3	4.66
500°F	143.7	4.74
MOT (807°F)	206.8	11.93
Contractor B: Maximum Wall Thickness = 0.520 in. Longitudinal Specimens		
Temperature	K_{Ic} (Fracture Toughness)	$5(K_{Ic}/YS)^2$ = Minimum Wall Thickness
	(Ksi$\sqrt{in.}$)	(in.)
-40°F	189.2	8.94
75°F	176.9	7.82
250°F	154.1	6.59
500°F	172.5	9.88
MOT (662°F)	167.4	9.29

TABLE II. (CONT'D)

Transverse Specimens		
Temperature K_{Ic} (Fracture Toughness) $5(K_{Ic}/YS)^2$ = Minimum Wall Thickness		
	(Ksi$\sqrt{in.}$)	(in.)
-40°F	146.1	5.45
75°F	147.1	5.52
250°F	135.9	5.02
500°F	125.3	5.27
MOT (662°F)	132	4.45
Contractor C: Maximum Wall Thickness = 0.432 in. Longitudinal Specimens		
Temperature K_{Ic} (Fracture Toughness) $5(K_{Ic}/YS)^2$ = Minimum Wall Thickness		
	(Ksi$\sqrt{in.}$)	(in.)
-40°F	68.9	0.742
75°F	112.1	1.96
250°F	96.0	1.60
500°F	112.3	4.19
MOT (783°F)	121.7	3.25
Transverse Specimens		
Temperature K_{Ic} (Fracture Toughness) $5(K_{Ic}/YS)^2$ = Minimum Wall Thickness		
	(Ksi$\sqrt{in.}$)	(in.)
-40°F	68.4	0.651
75°F	99.2	1.37
250°F	87.1	1.23
500°F	92.2	1.53
MOT (783°F)	94.5	1.99

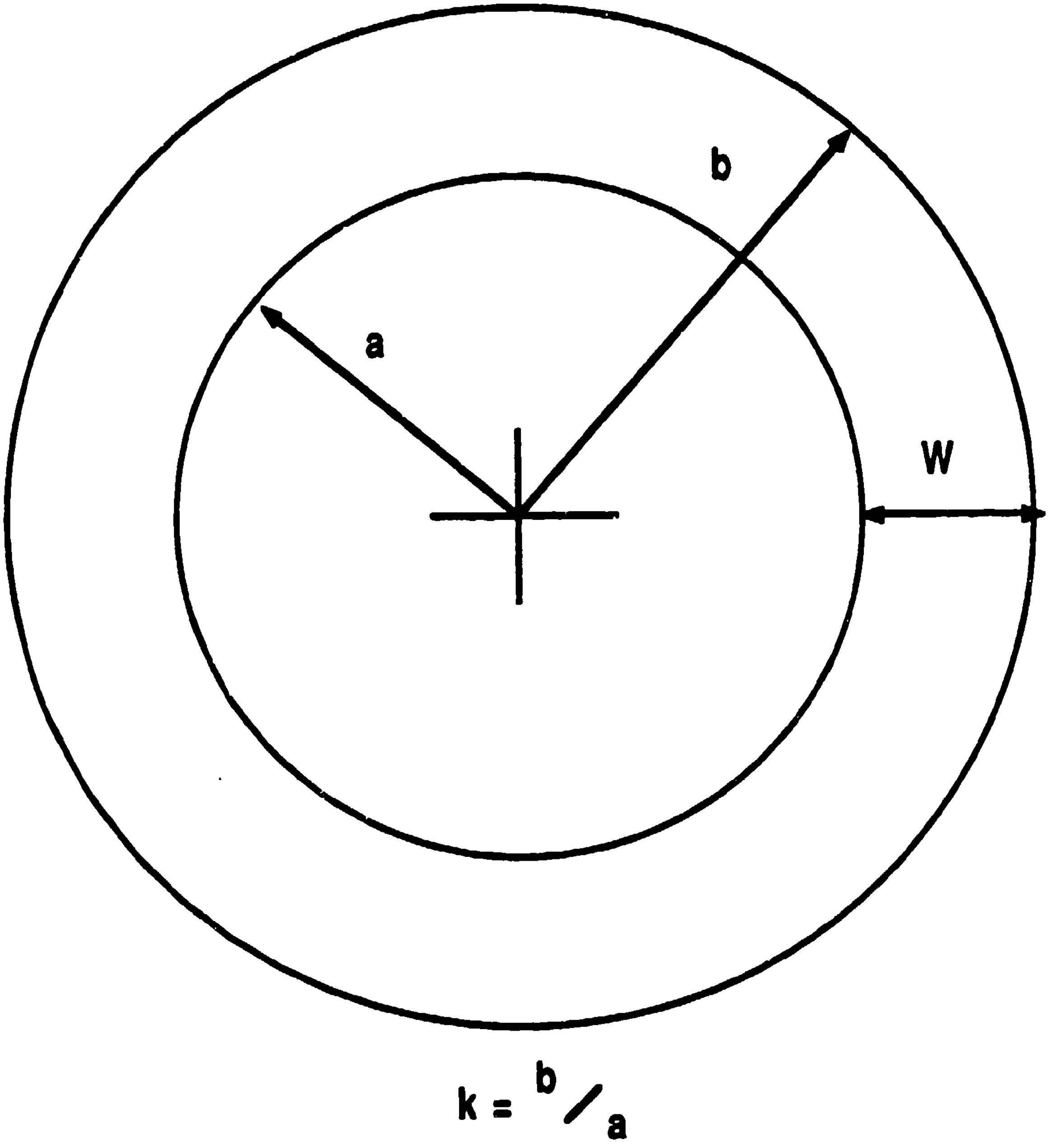

Figure 1. Schematic section of a mortar.

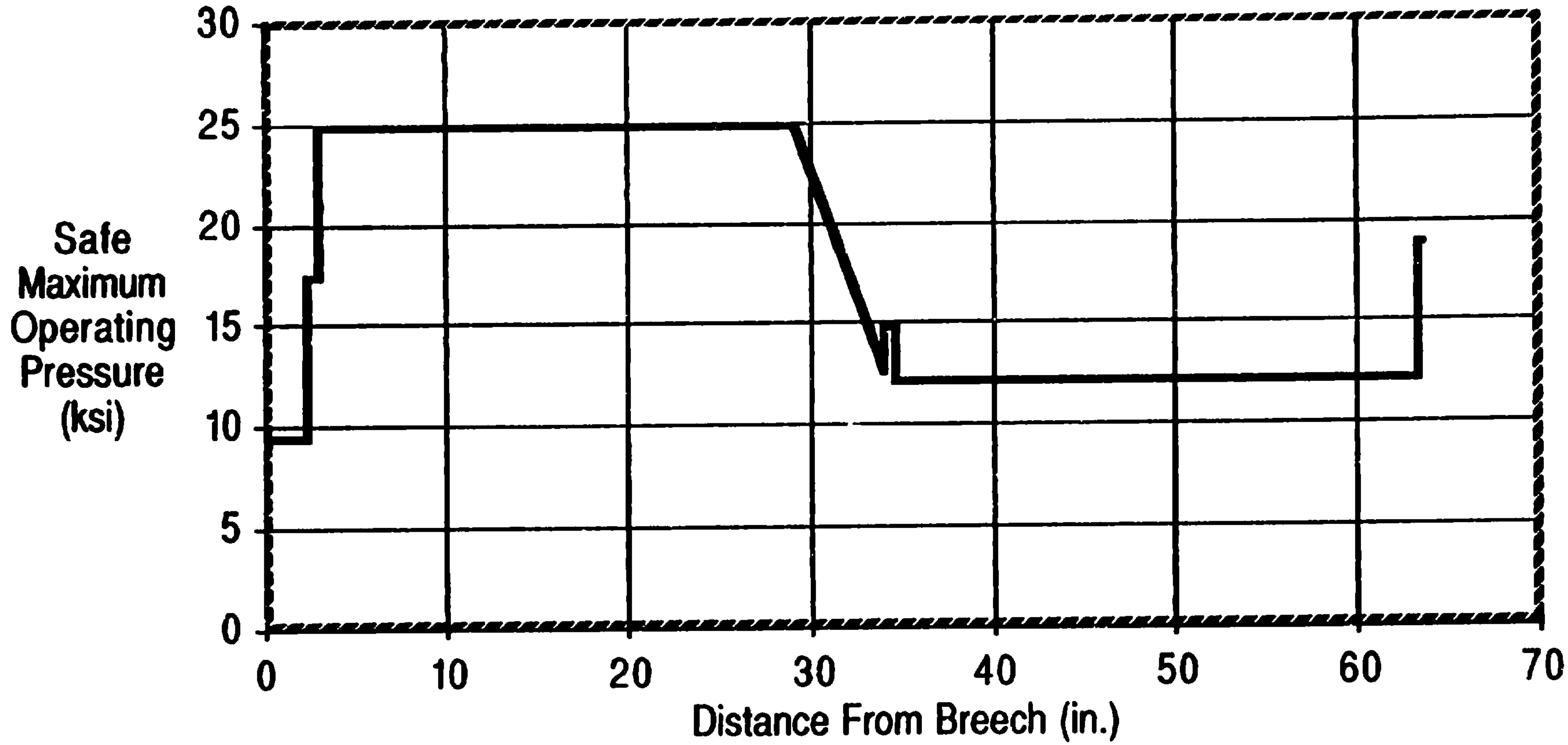

Figure 2. Contractor A, safe maximum operating pressure at 807°F - 0.2 percent offset yield strength = 133.9 Ksi.

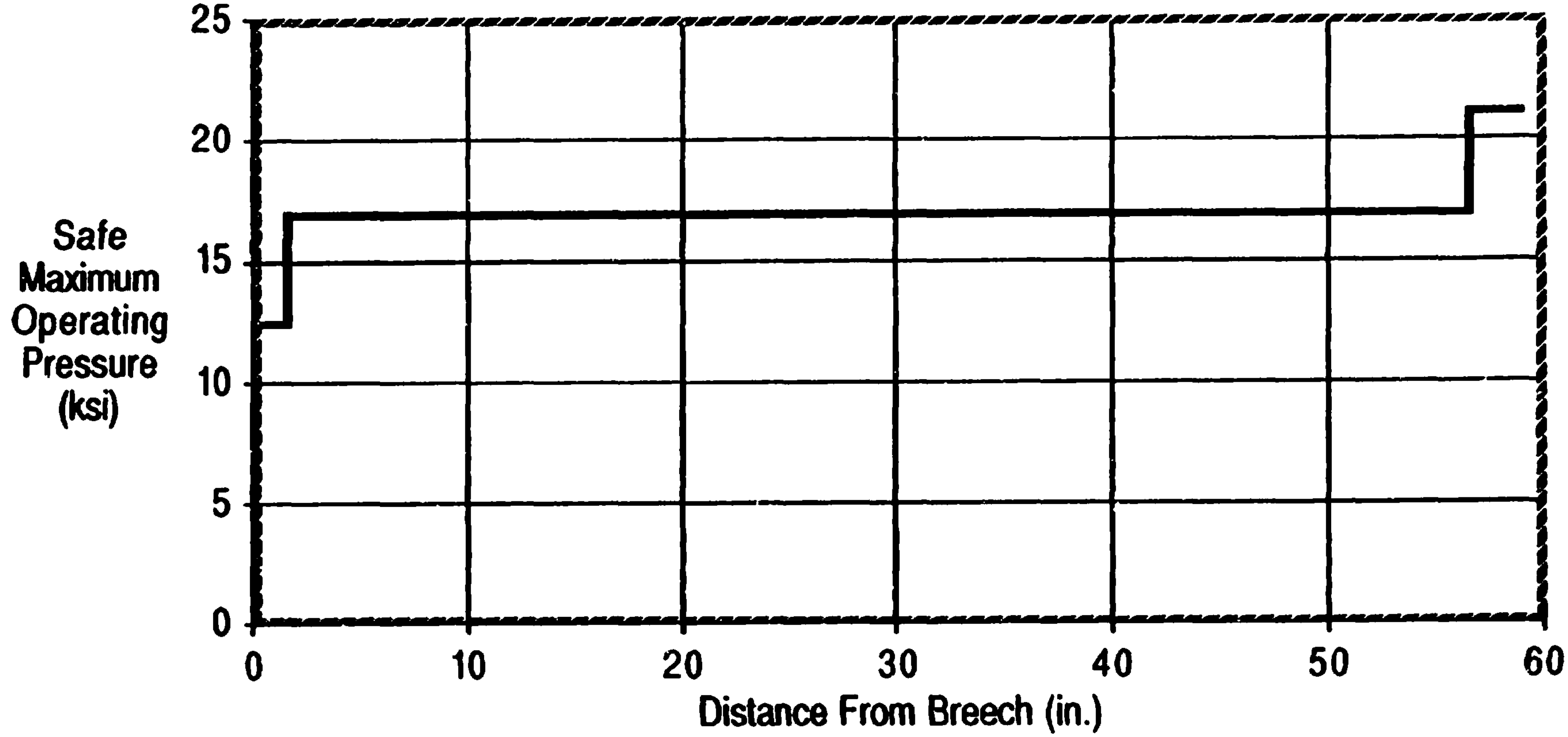

Figure 3. Contractor B, safe maximum operating pressure at 662°F - 0.2 percent offset yield strength = 119.5 Ksi.

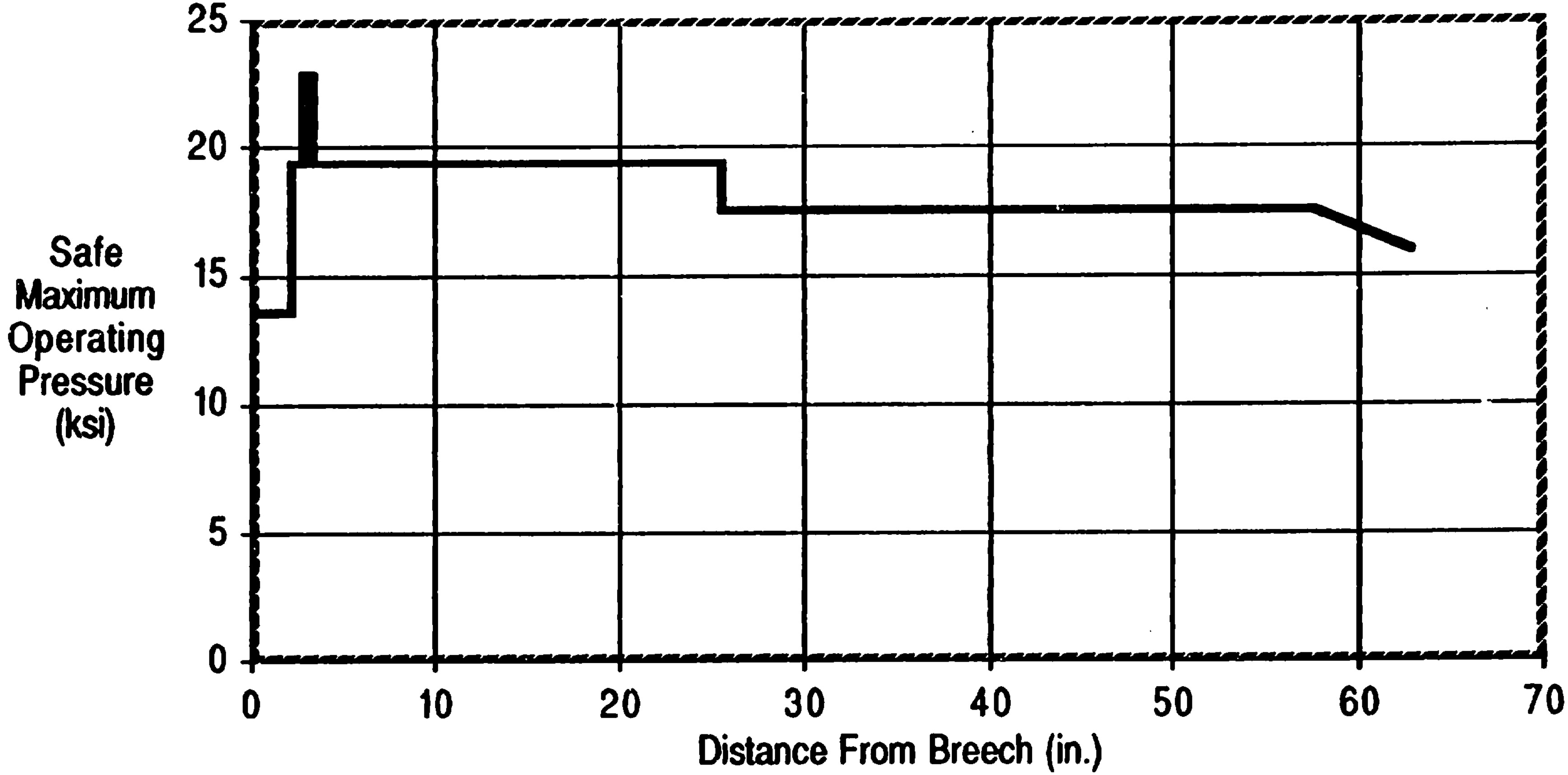

Figure 4. Contractor C, safe maximum operating pressure at 783°F - 0.2 percent offset yield strength = 149.8 Ksi.

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